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Fire and Season of Burn Affect Recruitment of the Invasive Exotic, *Potentilla recta*

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Summary

Fire-caused disturbance, has many beneficial effects on semi-arid grassland systems but also has the potential to facilitate exotic plant invasion. Managers of natural areas must decide whether and how to use fire to the best advantage in the face of this dilemma. *Potentilla recta* is an exotic plant invading Dancing Prairie Grassland Preserve in northwest Montana. We used a complete factorial design with all combinations of spring burn, fall burn, no burn, herbicide and no herbicide to determine the effects of fire, season of burn and their interaction with herbicide on the recruitment and population growth of *P. recta* over a five-year period. Disturbance by pocket gophers was an unplanned factor in the MANOVA models. Recruitment of *P. recta* was higher in burn plots compared to controls the first year after the fire, but this did not lead to significant population growth in subsequent years, possibly due to the drier than normal conditions that prevailed during the study. Recruitment was higher in fall compared to spring burn plots. The presence of gophers had no detectable effect on the density of small or large plants. Herbicide effectively eliminated *P. recta* from sample plots for 3-5 years. Density of *P. recta* was greater in herbicide plots that were burned than those that were not by the end of the study. Results suggest that prescribed fire will have a positive effect on the germination of *Potentilla recta*, but this will not always lead to increased population growth. Prescribed fire may reduce the long-term efficacy of herbicide applied to control *Potentilla recta* and will be most beneficial at Dancing Prairie when conducted in the spring rather than the fall. Results of prescribed fire on weed invasions in semi-arid environments will be difficult to predict because they are strongly dependent on stochastic climatic events.

Introduction

Fire is an important process in many North American landscapes (Kozlowski and Ahlgren, 1974). Fire can remove much or all aboveground biomass, increasing light penetration to the soil surface and often raising surface temperatures (Hulbert 1988, Peet et al. 1975). Combustion of

live and dead fuels or removal of litter layers may result in enhanced nutrient availability (Knapp and Seastedt 1986, Dudley and Lajtha 1993, Brewer, 1995). These changes often result in increased productivity and flowering (Grigore and Tramer 1996, Hartnet and Richardson, 1989, Menges 1995). Fire may also stimulate germination of species adapted to recently fire-disturbed sites (Daubenmire 1968, Glenn-Lewin et al. 1990, Leach and Givnish 1996). In grassland and shrubland ecosystems managers use prescribed fire to deter woody plant encroachment and promote species diversity by removing litter and creating safe sites for regeneration (Loucks 1968, Good 1981, Steuter et al. 1990). In several instances, natural area managers have used prescribed fire to enhance population viability of rare or endangered species (Hessl and Spackman 1995).

The disturbance caused by fire, though beneficial to many system processes, also has the potential to facilitate exotic plant invasion (Hobbs and Huenneke 1992). The same effects that cause an increase in native diversity (canopy and litter removal) may also result in increased invasion by exotics (Maret and Wilson 2000). *Centaurea maculosa* (spotted knapweed) increased following fire in both grassland and forested environments in eastern Washington and western Montana (Sheley et al. 1999). Fire enhanced the invasion of exotics in Australian *Banksia* woodlands and sclerophyll forests (Milberg and Lamont 1995, Hobbs and Aikens 1990, Briese 1996). Controlled burning enhanced the establishment of *Imperata cylindrica* (cogongrass) in Mississippi pine savannas (King and Grace 2000). Prescribed fire in California coastal chaparral caused an increase in the invasive *Carpobrotus edulis* (ice plant; Zedler and Scheid 1988). Fire can cause an increase in exotics that threaten endangered species (Hessl and Spackman 1995). On the other hand, fire has also been used to control plant invaders in some grassland systems by reducing the number of seedlings (MacDonald et al. 2001, Sheley and Petroff 1999) or damaging mature plants while native competitors are dormant (Curtis and Patch 1948). Effects of fire on weed invasion will depend on the presence of a seed source as well as the biology of the invaders and the community.

The season in which fire occurs may affect how plant species and communities respond (Abrahamson 1984, Biondini et al. 1989, Howe 1995, Cobb et al. 1996). Early and late dormant-season fires are commonly used in natural areas management (Steuter et al. 1990) and may have different effects on vegetation. The interaction of season-specific fire intensities and plant phenology determine how season of burn affects different species (Meyer and Schiffman 1999). Prescribed fire during the spring enhanced recruitment of native plants more than fall burning in western North America (Cobb et al. 1996, Lesica 1999) and Australia (Hobbs and Atkins 1990). Late spring and fall burns were more effective at increasing the cover of native plants without weed invasion than winter burns in California grasslands (Meyer and Schiffman 1999). Summer but not early spring fire reduced the density of weedy *Alliaria petiolata* in Illinois upland forest (Schwartz and Heim 1996). Season of burn could be an important factor when prescribing fire for natural areas where weeds are present.

Herbicide application is a commonly used management tool to control invasive exotics in wildlands and natural areas (Reinartz 1997, Litt et al. 2001). There is evidence that broad-leaf herbicides have increased efficacy directly following fire for some species (Lacey et al. 1995, Thill et al. 1999). The disturbance associated with prescribed fire may also have more long-term effects on the efficacy of herbicide treatment. However, we know of no long-term studies on the interaction between effects of fire and herbicide on invasive exotics.

Managing natural areas must balance protecting indigenous ecosystem processes and species while minimizing the impacts of human activity, including the invasion of nonindigenous species (Cole and Landres 1996). Many stewards of grasslands and other fire-evolved ecosystems in Montana and elsewhere must decide whether to use prescribed fire, at what season to burn, and how to integrate fire into their weed management programs. These are among the decisions faced by managers at The Nature Conservancy's Dancing Prairie Preserve in northwest Montana where the invasive exotic plant, *Potentilla recta*, is threatening the ecological integrity of the native

fescue grasslands and the largest known population of the federally-listed threatened plant, *Silene spaldingii*.

Potentilla recta (sulphur cinquefoil) is native to Europe and Asia and was introduced into North America prior to 1900. It has since spread through much of Canada and the U.S. as far south as Texas (Werner and Soule 1976). *Potentilla recta* is a rosette-forming perennial, developing a massive, woody root (Werner and Soule 1976). In western Montana, flowering begins in June and continues through July in some areas. In southern Canada, an average plant produced ca. 1,650 seeds per plant in one year (Werner and Soule 1976); however, reproductive allocation is variable among years and habitats (Soule and Werner 1981). Vegetative reproduction does not occur. Seeds collected in August germinate readily in October with warm/dark-light (55%) and warm-cold/dark-light (70%) treatments. Only ca. 5% germinate in the dark (Lesica, unpublished data). Seeds are believed to remain viable in the soil for at least three years (Rice 1999). *Potentilla recta* is among the most invasive exotics in the Northern Rocky Mountains. It has spread to over half of Montana as well as significant portions of Idaho, Washington, Wyoming and Oregon (Rice 1999). Invasion and spread are most rapid in disturbed areas, but *P. recta* is capable of invading relatively undisturbed sites (Lesica, unpublished data). The herbicides picloram and 2,4-D have been demonstrated effective in controlling *P. recta*, but continuous retreatment is required (Rice 1999). No biological control agents for *P. recta* have been identified. Within the past several years *Potentilla recta* has greatly increased in portions of The Nature Conservancy's Dancing Prairie Preserve in northwest Montana.

Fire played an integral part in the vegetation dynamics of Intermountain grasslands (Antos et al. 1983, Koterba and Habeck 1971). We believe that fire should be restored to Dancing Prairie Preserve to minimize *Pinus ponderosa* (ponderosa pine) invasion and reduce litter to invigorate native bunchgrasses and enhance recruitment of native forbs including *Silene spaldingii* (Lesica 1999). However, an increase in *Potentilla recta* is a potential adverse consequence of prescribed fire. We conducted our study to determine the effect of prescribed fire on the

population growth of *Potentilla recta* for five years following the burn. Burns were conducted in both spring and fall to assess differences in response of *P. recta* to season of fire. We also included herbicide application in our study design to determine how fire affects the long-term efficacy of herbicide application.

Study Site

Dancing Prairie Preserve is in the Tobacco Plains, a narrow glacial valley at 825 m, 6 km north of Eureka in northwest Montana (Township 37N, Range 27W, Section 26). Mean annual precipitation was 377 mm and mean July and January temperatures were 19.4° and -5.4°C respectively at Eureka (Western Regional Climate Center data; www.wrcc.dri.edu). The preserve consists of 250 ha of fescue-wheatgrass-needlegrass grasslands developed on rolling glacial topography. Grasslands of western Montana are transitional between Palouse Prairie typical of eastern Washington and Oregon and grasslands of the Northern Great Plains (Antos et al. 1983). *Silene spaldingii* occurs in the bottom of shallow swales and on cool slope exposures with relatively deep soil. Common grasses in these habitats are *Festuca scabrella*, *F. idahoensis*, and *Poa pratensis* (Lesica, 1997); nomenclature follows Hitchcock and Cronquist (1973). Fires ignited by lightning as well as Native Americans played an important role in structuring the vegetation of the Tobacco Plains by preventing the establishment of woody vegetation (Koterba and Habeck 1971, Dorey 1979, Barrett and Arno 1982). Pocket gophers (*Thomomys talpoides*) are common at Dancing Prairie Preserve. They consume plants, and their diggings disturbs the soil. Pocket gopher activity can have large effects on vegetation where they are common (Huntly and Inouye 1988, Martinsen et al. 1990) and may facilitate the invasion of weeds (Rice 1985, Wolfe-Bellin and Moloney 2000). The effect of pocket gophers on *Potentilla recta* is not known.

Methods

Field Methods

We used a complete factorial design with all combinations of spring burn, fall burn, no burn, herbicide and no herbicide. We established 54 circular plots in areas infested with *Potentilla recta* in May 1996. Each plot was permanently marked by a post at the center. The amount of plant litter (fuel) in each plot was classified as low, medium or high. Plots were stratified by amount of litter and location and then randomly assigned to one of the six treatment combinations. Each of the six treatments was originally replicated nine times. However, five of the herbicide plots were not treated with herbicide as planned, resulting in an unbalanced design: fall burn/herbicide (7), spring burn/herbicide (7), no burn/herbicide (8), fall burn/no herbicide (11), spring burn/no herbicide (11) and no burn/no herbicide (10).

Picloram (Tordon) herbicide at the recommended rate of 1 pint/acre was applied around the center post of each herbicide plot to a radius of 2-3 meters on 10-11 June 1996. Effects of the herbicide treatment did not affect the density of *P. recta* during the first recording period on 11-12 July 1996. Each burn plot was burned to a radius of 3 meters from the center post. Fall burn treatments were applied on 17 October 1996; ignition occurred throughout each plot. Fire intensity was judged to be moderate based on litter remaining in the plots litter. Spring burn treatments were applied 7-8 April 1997; fuels were compacted, and fires burned somewhat cooler than fall burn treatments.

In each plot we counted the number of *Potentilla recta* plants in a 1-meter-radius circular plot around the center post. Plants were counted into one of two size classes: small (1-4 leaves) and large (≥5 leaves). We chose these classes because a demography study of *P. recta* at the same site indicates that plants in the small class are usually less than 1 year old, while larger plants are likely to be older (Lesica, unpublished data). We noted the presence of pocket gopher mounds in sample plots each year throughout the study. Sample plots for which gopher activity

was recorded any time during the study were considered affected. Plots were read each year in mid-July 1996-2001.

Data analysis

We evaluated the effect of fire, season of fire and pocket gopher disturbance on density of *Potentilla recta* in each year following treatment using Multivariate Analysis of Variance (MANOVA) with density of *P. recta* in July 1996 as a covariate in the models to account for differences between plots at the start of the experiment. Separate analyses were conducted for the two *P. recta* size classes. Each MANOVA was followed by three binomial contrasts to test for differences attributable to burning (spring + fall versus control), differences between season of burn (spring versus fall), and presence of gopher disturbance. Each significant MANOVA contrast test was followed by univariate F-tests to determine which years were responsible for the effects.

The majority of plots treated with herbicide had no *Potentilla recta* plants, so these data could not be analyzed with parametric tests. We used a Mann-Whitney non-parametric test to assess the effect of fire on *P. recta* density at the end of the study in herbicide-treated plots.

Results

Background population trends

The density of small *Potentilla recta* plants in control plots was highest in 1996, began to decline in 1997 (paired t=3.6, P=0.006), then declined sharply in 1998 (t=2.5, P=0.034), and remained low throughout the rest of the study (Fig. 1A, open bars). The density of large *P. recta* plants declined appreciably in 1997 (t=2.4, P=0.038), then increased gradually to initial levels at the end of the study (Fig. 1B, open bars). Population declines recorded in July 1997 were associated with below average precipitation for April and May of that year. Annual precipitation

for the area was 15-30% below average for 1999-2001 (Western Regional Climate Center data; www.wrcc.dri.edu).

Effect of fire

Only plots that did not receive herbicide treatment were employed in the analyses of the effects of fire on *P. recta*. Fire had a significant effect on the density of small *P. recta* over the course of the study; however, this effect was detectable only for the first year following the treatment (Table 1, Fig. 1A). Mean density of small *P. recta* declined by 47% in control plots between 1996 and 1997 but only 26% in burn plots (fall + spring). Density of small *P. recta* declined equally between 1997 and 1998 in both burn and no-burn plots. Small plants continued at low levels in both treatment and control plots for the remainder of the study (Fig. 1A). There was no detectable effect of fire on the density of large *Potentilla recta* plants (Wilk's λ=0.735, F=1.51 P=0.228; Fig. 1B).

Effect of fire season

Results of MANOVA indicate that there was a marginally significant effect of season of burn on the density of small *Potentilla recta* plants over the course of the study (Table 1, Fig. 2A). Mean density of small plants declined 42% in spring burn plots but only 12% in fall burn plots in the first year following the treatments. However, this trend was reversed for the remainder of the study. Density of small *P. recta* plants declined 47% in spring burn plots but 77% in fall burn plots between 1997 and 1998. Between 2000 and 2001 small plants increased slightly in spring burn plots but declined 72% in the fall burn plots (Table 1, Fig. 2A). Results of MONOVA indicate there was no detectable effect of season of fire on the density of large *Potentilla recta* plants (Wilk's λ=0.702, F=1.78, P=0.161; Fig. 2B).

Effect of pocket gophers

Pocket gopher diggings were observed in 17 of the 32 no-herbicide plots between 1997 and 2001. There was no detectable effect of gophers on the density of small (Table 1) or large (Wilk's λ=0.795, F=1.08, P=0.398) *Potentilla recta* plants over the course of the study.

Effect of herbicide

Herbicide application was very effective at killing *Potentilla recta* plants. In 1997 and 1998 *P. recta* plants were completely absent from plots receiving herbicide treatment in 1996. Two plots each had a single *P. recta* plant in 1999 (9%). There were three plots with *P. recta* plants in 2000 (14%) and five plots in 2001 (23%), all of which had been burned. Density of *P. recta* was marginally higher in herbicide plots that had been burned compared to those that had not at the end of the study (U=76, P=0.063). Season of prescribed fire had no effect on the density of *P. recta* in herbicide plots (U=16, P=0.204).

Discussion

Fire

Fire stimulated recruitment by *Potentilla recta* the first year following burn treatments; however, this effect disappeared the following year and thereafter. Precipitation was above average in 1995 and 1996, and this may have accounted for the large number of small (mostly newly recruited) plants at the start of the study. Grassland fires may also result in warmer soil temperatures and increased available nutrients (Knapp and Seastedt 1986, Hulbert 1988) which could cause enhanced germination and recruitment (Daubenmire 1968, Glen-lewin et al. 1990). Density of small plants declined between 1996 and 1997, more so in control compared to burn plots. This decline was associated with below-average precipitation in April and May of 1997, the time when plants are initiating growth. The loss of small *P. recta* plants continued between 1997 and 1998, although there was no longer a significant effect of fire. The decline in small plants in

1998 was accompanied by an increase in large plants (Fig. 1). There was above-average precipitation in 1998, so much of the decline in small plants was likely due to growth into the larger size class rather than attrition. Drought conditions prevailed at the study site since 1998, and density of small *P. recta* plants remained low. Increased recruitment of small plants in burn plots compared to controls in 1997 never resulted in a significant increase of large plants in burn plots.

The short-term increase of *Potentilla recta* due to fire was not indicative of the long-term effects. *Potentilla recta* sample populations failed to increase despite enhanced recruitment, possibly due to climate-induced mortality. We believe that a larger proportion of the *P. recta* seedlings would have survived and grown to maturity had the weather been more benign. Had this been the case we would have observed a long-term positive effect of fire on *P. recta* population growth. Our results suggest that disturbance-induced regeneration may depend on stochastic factors such as climate or the presence of propagules (McCune and Allen 1985, Wood and del Moral 1987, Maret and Wilson 2000, Pendergrass et al. 1999). Similar results were observed in Australian eucalypt forests where fire enhanced germination of *Hypericum perforatum* (St. John's-wort), but this did not contribute to increased population growth (Briese 1996). Our results indicate that long-term studies are needed to accurately determine the effects of disturbance on population growth.

Season of fire

Our study provides evidence that the effects of fire on *Potentilla recta* differed between spring and fall burns. Density of small P. *recta* increased more in fall burn plots the first year after the treatments. However, small *P. recta* plants fared better in spring burn plots thereafter. Our observations of residual litter suggest that fire intensity was greater for the fall burns. Greater disturbance associated with fall fire may have induced a larger proportion of the seed bank to

germinate immediately compared to spring fire, depleting the store of seeds available for germination in subsequent years.

Response to season of prescribed fire may depend on germination requirements. Seeds of *Silene spaldingii* and *Erodium cicutarium* require stratification and generally germinate in late winter or spring (Lesica 1993, Grime et al. 1981). Both species have a more positive response to spring compared to fall burns (Lesica 1999, Meyer and Schiffman 1999) . Seedlings of the shrub, *Chrysothamnus molestus*, were more abundant following a spring burn compared to fall burn (Cobb et al. 1996). Germination requirements for this species are unknown, but seeds of the related shrub, *C. nauseosus,* require cold stratification to germinate (Khan et al. 1987). *Potentilla recta* seeds germinate without stratification, suggesting that many seeds may germinate that fall if conditions are suitable, and *P. recta* had a more positive response to fall burning. These results suggest that a disturbance that coincides with the normal germination time may result in more recruitment than one that does not. However, *Lactuca serriola* does not follow this pattern; it germinated better following a spring burn compared to a fall burn (Meyer and Schiffman 1999), but its seeds do not require stratification and often germinate in fall (Prince and Carter 1985). Further research on the relationship between germination requirements and fire season could lead to fire prescriptions that minimize the increase of weedy plants. Whatever the cause, our results suggest that season of prescribed fire can affect seedling recruitment.

Pocket gophers

There was no indication that pocket gophers had any effect on the density of either small or large *Potentilla recta* plants over the course of the study. Our findings are at odds with most published studies. Forb seedlings were generally more common on bare ground created by gopher disturbance in shortgrass prairie (Martinsen et al. 1990). Germination of *Medicago lupulina* seeds was lower on gopher mounds in tallgrass prairie, but growth and survival was greater (Wolfe-Bellin and Moloney 2000). Abundance of forbs generally increases with pocket

gopher grazing and digging (Ellison and Aldous 1952, Martinsen et al. 1990, Wolfe-Bellin and Moloney 2000). However, freshly excavated subsoil is lower in available nutrients and organic matter than surface soil (Huntley & Inouye 1988; Spencer et al. 1985). It is likely that seedlings germinating on gopher mounds may not survive in these harsh open sites during drought years such as occurred during our study. Furthermore, pocket gophers harvest and bury existing vegetation as well as creating open sites for seedling establishment (Huntley and Inouye 1988). Dozens of marked *Potentilla recta* individuals disappeared beneath gopher mounds in a demography study at Dancing Prairie (Lesica, unpublished data). There may have been an approximate balance between the positive and negative effects of pocket gophers on *P. recta* over the course of our study.

Herbicide-fire interaction

Fire had a negative effect on the long-term efficacy of herbicide application on *Potentilla recta.* The effects of fire on *P. recta* in the herbicide plots did not become evident until 3-5 years after the treatments when it began to reinvade. Picloram is a growth-regulating hormone mimic that kills germinating seedlings for 2-4 years after application (Bussan and Dyer 1999, Rice 1999). Higher soil temperatures associated with the fire or solar heating of the blackened soil surface may have reduced the residual activity of the herbicide, allowing earlier germination of *P. recta* seeds in burn plots. Efficacy of herbicide on mature plants can be enhanced by burning the vegetation prior to application, probably by removing litter and stimulating growth (Lacey et al. 1992, 1995, Thill et al. 1999). Further research is needed on the effect of post-herbicide fire on the residual activity of the herbicide.

Stewardship applications

Results from our study suggest that prescribed fire will have a positive effect on the germination of *Potentilla recta.* However, enhanced germination may not always lead to

increased population growth. We believe that prescribed fire will usually cause a flush of *P. recta* germination. However, this will lead to an increase in mature plants only if the climate in subsequent years is conducive to survival. Burning during a drought cycle should help minimize the threat of increased *P. recta*; however, desirable native plants may also fail to achieve the enhanced recruitment that is often associated with fire. Ultimately climate will play a large role in dictating the results of prescribed fire in a semi-arid environment. Prescribed fire may reduce the long-term efficacy of herbicide applied to control *Potentilla recta*, necessitating earlier reapplication in burned areas.

Season of prescribed fire can be critical for grassland management (Howe 1995). Burning in the fall produced a larger first-year flush of *Potentilla recta* germination than spring burning (Figs. 2A), suggesting that spring prescribed fire is preferable. Furthermore, recruitment of the endangered plant, *Silene spaldingii*, was greater following spring compared to fall burning at Dancing Prairie Preserve (Lesica 1999). Finally, hotter fall burns are more detrimental to *Festuca scabrella*, the dominant grass on the Preserve (Redmann et al. 1993), especially if there have been many years of fire exclusion (Antos et al. 1983). All evidence available at this time suggests that prescribed fire will be most beneficial at Dancing Prairie when conducted in the spring rather than the fall.

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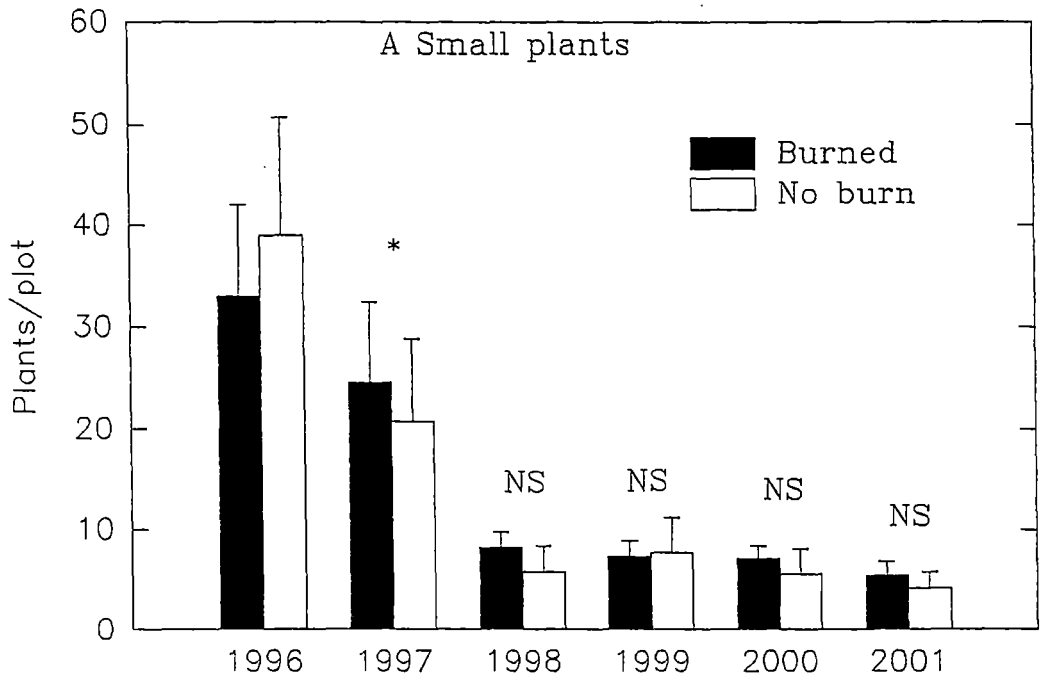
Table 1. Effect of fire and presence of gophers on mean density of **small** *Potentilla recta* plants by MANOVA followed by three contrast tests for the effect of fire, season of fire and gophers. Contrast degrees of freedom are 5 and 21 for tests and error respectively. Each contrast test was followed by univariate F-tests each with 1 and 25 degrees of freedom for the test and error respectively.

Effect	Wilks' λ	*F*	*P*
Fire	0.600	2.81	0.043
Season	0.656	2.20	0.092
Gophers	0.674	2.04	0.115

	Effect of fire		Effect of season		Effect of gophers	
Year	*F*	*P*	*F*	*P*	*F*	*P*
1997	**5.16**	**0.032**	**4.77**	**0.038**	0.32	0.578
1998	2.55	0.123	3.11	0.090	3.43	0.076
1999	0.17	0.682	1.01	0.324	1.63	0.213
2000	1.74	0.200	0.24	0.628	0.05	0.822
2001	0.85	0.367	**5.76**	**0.024**	0.00	0.981

Figure 1. Mean number of small (A) and large (B) *Potentilla recta* plants in burned (spring and fall) and unburned sample plots before (1996) and after fire treatments. Effect of fire was determined by univariate *F*-tests; **P*<0.05.



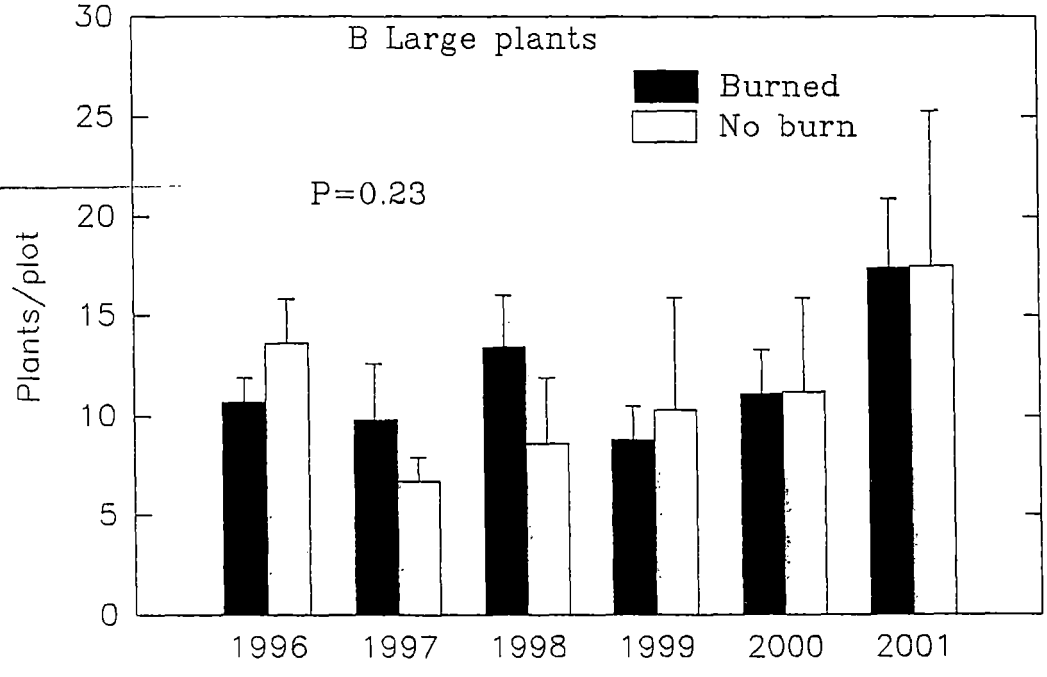


Figure 2. Mean number of small (A) and large (B) *Potentilla recta* plants in sample plots burned in spring and fall before (1996) and after fire treatments. Effect of fire was determined by univariate *F*-tests; **P*<0.05.